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The effect of alternative keyboards on discomfort and typing kinematics

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List of Terms and Abbreviations

CRF – Computer Rating Form

Forearm pronation – forearm posture in which the palm is turned downward.

FSA – Fixed, Split-Angle (refers to the alternative keyboard used in the study [Microsoft Natural])

Kinematics – the science of describing the motion. Results for this study are reported as joint angles.

LUE – left upper extremity

MCP – metacarpophalangeal joint (“knuckle” of the hand)

MSD – musculoskeletal disorders

NRS – numerical rating scale

RUE – right upper extremity

ST – Standard (refers to the standard flat keyboard used in the study [Lenovo Model No. Ku-0225])

UE – upper extremity

WDS – Weekly Discomfort Survey

Wrist extension – wrist posture in which the wrist bends toward the back of the hand (“stop” position).

Wrist ulnar deviation – wrist posture in which the wrist bends toward the small finger.

Abstract

Title: The effect of alternative keyboards on discomfort and typing kinematics

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Non-neutral postures of the arm/hand during keyboard operation are considered to be risk factors for musculoskeletal disorders (MSD) and musculoskeletal discomfort. Alternative keyboards have built-in angles designed to eliminate non-neutral postures. They have become the number one selling keyboards in the US based on the assumption that they reduce discomfort by eliminating these types of postures. While studies demonstrate that alternative keyboards improve non-neutral postures, there are few studies that suggest that they reduce discomfort.

This crossover, randomized trial evaluated the effectiveness of an alternative, fixed, split-angle (FSA) keyboard (Microsoft Natural) compared to a flat standard (ST) keyboard. Eighty-five participants were randomly assigned to either Group 1 (ST keyboard switched to FSA keyboard) or Group 2 (FSA switched to ST keyboard). Participants documented discomfort of the neck, back, and right/left arm/hand weekly for 12 months (5-6 months per keyboard), and identified the usability of their current keyboard monthly. We obtained kinematics data on participants' postures during keyboard use at baseline, 5-6 months, and 12 months.

Eighty-five participants enrolled in the study, 44 in Group 1 and 41 in Group 2. Data analyses were completed on 77 participants. Participants were primarily female, aged 44 years (SD = 12.4 years) and worked an average of 6.2 hours per day at the computer. Ninety-three percent reported a level 2 or greater discomfort, on a scale to 10, for the neck, 85.7% reported discomfort in the back, and 89.6% and 59.7% reported discomfort in the right and left arm/hands respectively.

There were no significant differences in the proportion of participants experiencing musculoskeletal discomfort when using the FSA keyboard in comparison to the ST keyboard after 5 to 6 months for all body parts. In all cases, a majority of participants started with discomfort, within 5 to 15 weeks the proportion had dropped to approximately 20%, regardless of the keyboard used. At 20-24 weeks the keyboards were switched. The proportion of participants with discomfort remained essentially stable at approximately 20% and continued at that level for the remainder of the study.

Participants reported that the ST keyboard was significantly more usable than the FSA keyboard even after 5 to 6 months of use, although half of the sample reported that they would prefer to continue using the FSA keyboard.

We completed kinematics data analyses on 40 participants. The FSA keyboard significantly reduced non-neutral postures for the forearm/wrist, but significantly increased non-neutral postures for left middle and ring and left/right little finger MCP flexion/extension. Kinematics remained stable from baseline to follow-up. There were few significant associations between discomfort and postures.

The results do not support the use of FSA keyboards to reduce the burden of discomfort for computer operators. FSA keyboards were no more effective at reducing musculoskeletal discomfort than flat ST keyboards. Additionally, many computer operators found FSA keyboards difficult to use. Given that FSA keyboards are no more effective than ST keyboards in reducing discomfort and potentially more difficult to use, employers should be cautious about purchasing and implementing FSA keyboards with their computer operators.

Section I

Computer keyboard use has long been considered a risk factor for musculoskeletal disorders (MSD)[1]. Research has found associations between non-neutral postures assumed during keyboard use and disorders such as carpal tunnel syndrome and tendonitis[2,3], as well as musculoskeletal discomfort[1]. Postures identified as risk factors include wrist ulnar deviation greater than 20 degrees, wrist extension greater than 15 degrees, and forearm pronation[4]. To reduce these risky non-neutral postures, designers have developed three separate adaptations to standard keyboards that address forearm pronation, wrist ulnar deviation, and wrist extension[5]. Alternative keyboard configurations combine one or several of these adaptations to reconfigure the overall shape of the keyboard.

Alternative keyboards are believed to reduce discomfort by eliminating non-neutral postures[3,6]. Numerous short-term, laboratory-based studies have demonstrated that they do significantly improve postures associated with discomfort[4,7]. Due to their perceived effectiveness, alternative keyboards have become the number one selling keyboards in the US[3]. They are frequently recommended to workers to help reduce or prevent MSD and discomfort. However, epidemiological research that has measured reductions of MSD or discomfort in relation to alternative keyboard use is limited, and generally does not find large effects related to alternative keyboard use[8-10]. This study examined the effects of long-term alternative keyboard use on computer users' reports of discomfort and on keyboard kinematics. We hypothesized that significantly fewer participants would report musculoskeletal discomfort when using a fixed, split-angle (FSA) (alternative) keyboard then when using our standard (ST), flat keyboard.

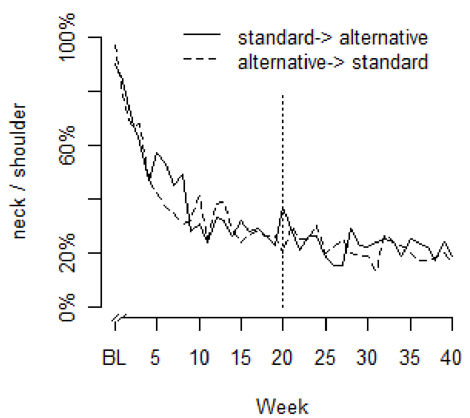

Figure 1: Weekly percentage of participants reporting discomfort for each body area for each keyboard during study period. There was no significant difference between the standard and alternative keyboard (keyboard x period, p = 0.73).

We used a randomized, 2-group crossover design. All 85 participants used both keyboards for 5-6 months. In Group 1, participants used the ST keyboard first, and then switched to the FSA keyboard (Microsoft Natural) at 5-6 months. In Group 2, the participants used the FSA keyboard first, and then switched to the ST keyboard at 5-6 months. Kinematics data on both keyboards were obtained at baseline, at 5-6 and 12 months of use using motion capture technology (VICON Systems).

Significant (Key) Findings:

Aim 1 - To examine the effectiveness of FSA keyboards at eliminating discomfort over 5 months.

Overall, there was no significant difference in the percentage of participants who eliminated their musculoskeletal discomfort between the ST and FSA keyboards. Figure 1 demonstrates findings typical of the study. Most participants started the study with musculoskeletal discomfort. After receiving their first study keyboard (ST or FSA), the percentage of participants with musculoskeletal discomfort rapidly reduced and leveled off at approximately 15 weeks into the study. This percentage remained essentially the same throughout the rest of the study. We had anticipated that when participants crossed over to their second study keyboard there would be an increase in the number of participants reporting discomfort for those switching to the ST keyboard, and continued/decreased percentage of those switching to the FSA keyboard. However, this did not occur. Participants also found the ST keyboard significantly more usable than the FSA keyboard, even after using the FSA keyboard for 5 to 6 months[11].

We completed secondary analyses on the data[12] to examine the moderating effect of the severity of baseline discomfort on the reduction of musculoskeletal discomfort at 6 months. In these analyses we only examined the first 5 months of the study, so these results reflect participants using only the first study keyboard. Results indicated that when baseline severity was included in the model, there was a significant difference for neck, right and left arm follow-up discomfort between those with none/mild baseline discomfort and those with moderate/severe baseline discomfort depending upon which keyboard was used. Those with moderate/severe baseline discomfort benefited more when using the FSA keyboard than those with milder discomfort.

Aim 2 – To examine the neutrality and stability of postures during keyboard use.

We compared the FSA and ST keyboard data at follow-up to determine which keyboard produced more neutral postures, and also examined the change in postures from baseline to follow-up for each keyboard to determine the stability of these results over 5 months on 40 of our participants. As with other research on the kinematics of keyboard use[4,13], the FSA keyboard significantly reduced all forearm/ wrist postures in comparison to the ST keyboard. However, the FSA keyboard had significantly higher left middle and ring finger flexion/extension values and left/right little finger flexion/extension values, as well as left index finger ulnar/radial deviation values. Thus, the FSA keyboard was more effective in reducing wrist/forearm postures, but was associated with increased non-neutral finger postures. Clinically, the FSA keyboard reduced wrist/forearm postures by 4.7 to 7.2 degrees, and the ST keyboard reduced finger postures by 1.5 to 4.3 degrees. Overall, these differences remained stable from baseline to follow-up.

Aim 3 – To identify which postures are associated with lower levels of musculoskeletal discomfort.

We found few significant associations between baseline musculoskeletal discomfort and postures. In general, increased finger extension on both the right and left sides was associated with more severe discomfort, particularly in the ring and little fingers.

Translation of Findings: FSA keyboards do reduce forearm/wrist postures considered to be risk factors for discomfort, but increase finger postures that may also affect discomfort. A greater proportion of computer operators receiving the FSA keyboard did not significantly improve their musculoskeletal discomfort compared to those who continued to use a ST keyboard. The FSA keyboard was found to be less usable than the ST keyboard, and many of our participants reported that it took several weeks to acclimate to the FSA configuration. While our secondary analyses suggests that the FSA keyboard may be effective for those with moderate to severe discomfort, this result was based on exploratory analyses and needs further examination to determine the robustness of the results. Thus, computer operators may not benefit from switching to a FSA keyboard. Employers should consider other methods to reduce musculoskeletal discomfort related to computer operation, including workstation redesign, employee training, and implementing a rest/stretching program[14,15]. This study found that sometimes simply changing from one flat keyboard to another may be sufficient to eliminate symptoms.

Outcomes/Impact: The potential outcomes of this study affect the implementation of interventions to reduce workplace risk for musculoskeletal discomfort. The results do not support the use of FSA keyboards to reduce the burden of discomfort in computer operators. They indicate that FSA keyboards are no more effective at reducing discomfort than flat ST keyboards and that many computer operators find FSA keyboards difficult to use and hard to acclimate to. FSA keyboards are more expensive than ST keyboards, and the cost of implementing these keyboards may not be warranted. This research does not indicate whether FSA keyboards are more effective than ST keyboards at preventing discomfort, but it does suggest that FSA keyboard may be effective for specific workers who have moderate to severe discomfort. Given that FSA keyboards are no more effective than ST keyboards in reducing discomfort for most computer operators, and potentially more difficult to use, computer operators should be cautious about purchasing and implementing FSA keyboards to address musculoskeletal discomfort.

Section 2 – Scientific Report

Background

Discomfort during computer use is common. Studies have reported that between 20% and 62% of computer users experience discomfort while using a computer[16,17]. Discomfort is a significant precursor to musculoskeletal disorders (MSD); in studies on the incidence of discomfort in computer users, between 68% and 81% of subjects with moderate to severe discomfort were subsequently diagnosed with MSD-UE[1,18]. Discomfort is a barrier to work productivity. Working with discomfort has been associated with absenteeism[19], and reduced productivity, resulting in a loss of an estimated $61.2 billion per year[20]. As over 77 million workers used a computer in the US at work in 2003[21] and that number appears to be growing, discomfort during computer use may place significant medical and financial burdens on both workers and employers. Given the association between discomfort and the development of MSD, it is imperative that we identify effective interventions to reduce or eliminate keyboard-related discomfort.

Current strategies to reduce computer-related discomfort and disorders have focused on implementing ergonomic interventions focused on reducing environmental causes of risk factors, one of the most common being non-neutral postures[2]. One common intervention for non-neutral postures is alternative keyboards. Alternative keyboards are angled keyboards that can reduce forearm pronation, wrist extension, and/or wrist ulnar deviation. Laboratory studies examining the efficacy of alternative keyboards have uniformly suggested that they can reduce non-neutral postures of the forearms and wrists[4,13]. Yet the few worksite studies that have examined the effectiveness of alternative keyboards in reducing discomfort have been equivocal[8,9,22]. No study has examined whether the postural changes reported in laboratory studies of alternative keyboard use occur at the keyboard users worksite. Studies have not examined if the changes in postures noted in laboratory keyboard studies are maintained over the long term. This study examines whether the implementation of an alternative keyboard for 5 to 6 months causes a reduction in discomfort and whether changes in postures that have been found with short term implementation of alternative keyboards in the laboratory are maintained when keyboards are used for 5 to 6 months. Finally, the study will examine the associations between postures and discomfort.

Specific Aims

Aim 1: To examine the effectiveness of FSA keyboards at eliminating discomfort over 5 months.

Aim 2: To examine the neutrality and stability of postures during keyboard use.

Aim 3: To identify which postures are associated with lower levels of musculoskeletal discomfort.

Method

Design and Participants: This study was a randomized, prospective, cross-over design in which participants were randomly assigned the order in which they used both a standard flat keyboard (Lenovo Model No. Ku-0225; Morrisville, NC) (ST) and fixed, split alternative keyboard (Microsoft Natural Ergonomics 4000 [version 1.0]) (FSA) which has both a fixed slant angle to reduce ulnar deviation and a fixed tilt angle to reduce pronation[4,7]. Participants were not informed which keyboard was considered to be more likely to reduce discomfort, and were encouraged to believe that both keyboards had the potential to reduce their symptoms. The Lenovo acted as a “placebo” for this study. It was different from participants’ regular keyboards in that it had a built in wrist rest, but was not angled in any way.

Eligible participants were adults aged 18-65 years who reported use of a work computer for at least 20 hours/week and who had neck, back, or upper extremity musculoskeletal discomfort of 2 or greater on a numerical rating scale [NRS] scale (0 = no discomfort, 10 = unbearable discomfort) during the preceding 6 months. Participants who had a history of serious upper-extremity trauma injury, rheumatic disorders, or current use of an alternative keyboard were excluded from the study.

Study variables: Descriptive variables. At baseline participants completed a demographic questionnaire which included questions about age, anthropometrics (e.g. height and weight), computer use, and general health. Baseline musculoskeletal discomfort was obtained for the neck/shoulder, back, and right/left elbow/forearm/wrist/hand

Symptoms and activity limitations were obtained weekly with the Weekly Discomfort Survey (WDS)[18,23]**.** Participants reported on their work schedule, medication use for pain, and discomfort in their neck/shoulder, back, and bilateral lower arms (elbows, forearms, wrists, and hands) using an 11-point numerical rating scale (0 = no discomfort/no limitations; 10 = unbearable discomfort/major limitations).

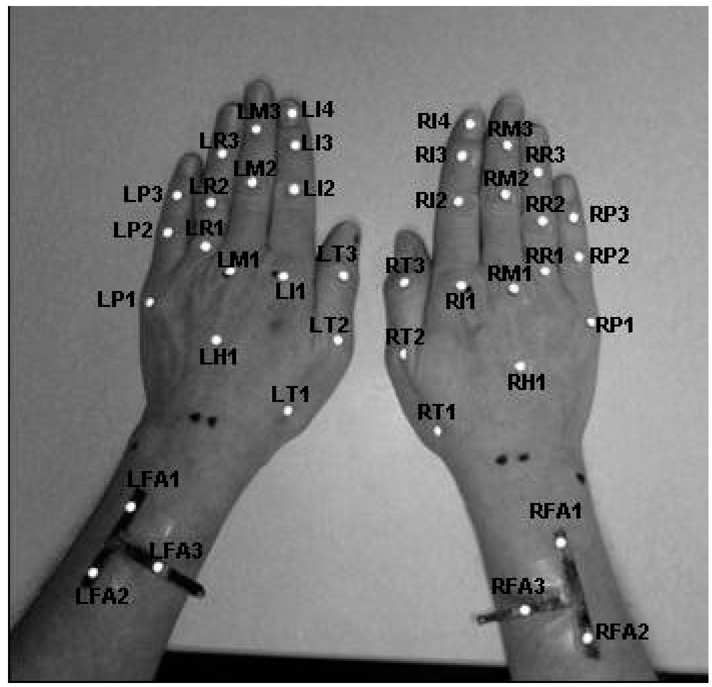

Figure 2: Motion capture passive marker set-up.

Keyboard usability was obtained monthly with the Computer Rating Form (CRF) which used a 5-point Likert-type scale (1 = strongly disagree; 5 = strongly agree). Participants indicated whether the keyboard was awkward to use; if it was easy to adapt to the keyboard design; the usability of different configurations such as the position of the letter keys, number keys and the spacebar; and whether they would prefer to continue to use the keyboard.

Kinematics typing data were captured at baseline, 6 months, and 12 months using a 5 camera Vicon™ motion capture system (VICON 460, Los Angeles, US): sampling frequency 100Hz. Forty-two passive reflective markers were attached to the dorsum of the hand (Figure 2). From these markers we calculated forearm pronation/supination, wrist and finger flexion/extension and ulnar deviation.

Procedure: Research personnel visited participants' worksite computer workstations and obtained demographic information as well as worksite set-up information (e.g. seat height, keyboard height and angle, monitor height). These data were used to configure the laboratory computer workstation to match the worksite computer workstation during kinematics data collection.

In the laboratory we obtained participants' typing kinematics for a generic standard keyboard and the first assigned keyboard (either the FSA or ST flat keyboard). Kinematic data were obtained for three 1-minute intervals over a 10 minute typing task in which participants transcribed a paragraph (4th grade reading level). After completing kinematic data collection, participants used their first assigned keyboard in their worksite computer workstation for 5 to 6 months. Between 5 and 6 months participants returned to the laboratory and follow-up kinematics data were obtained for the first assigned keyboard and baseline data for the second assigned keyboard. Participants used the second assigned keyboard for 5 to 6 months before returning to the laboratory one final time to record follow-up kinematics data on the second assigned keyboard.

During the 5 to 6 month trial period, data on discomfort severity were obtained online weekly with the WDS. Participants completed the baseline CRF after a trial period of approximately 10 minutes use on the new keyboard during the laboratory visit. Thereafter, the CRF was completed monthly. Data collection continued across both 5 to 6 month periods for a total of 1 year per participant.

Kinematic data were cleaned. Due to the complexity of tracking 42 markers while typing, data cleaning took, on average, 8 hours for each 1 minute collection period. Due to time constraints we cleaned 40 participants' data. Kinematics data were processed through a first order Butterworth low-pass filter with a cut-off frequency of 5Hz. Forearm, wrist, and finger postures were calculated (See appendix A)

Statistical analyses: Continuous demographic variables were summarized by mean and standard deviation, categorical variables were presented by count and percentage of total.

All participants completed at least 5 months of WDS and CRF data for each keyboard, but some did not complete a full 6 months, due to the logistics of obtaining the keyboard kinematic performance and switching from the first study keyboard to the second study keyboard. Therefore, we only analyzed data for the first 5 months of each period.

Although our hypothesis was to examine reductions in discomfort, the dependent variables of the numerical rating scales outcomes were not normally distributed. We, therefore, dichotomized our outcome into binary variables (discomfort/no discomfort). Thus, we had multiple binary data points for discomfort, and, due to the longitudinal cross-over design, these data points were auto-correlated. We used generalized estimating equations (GEE), a form of generalized linear modeling (GLM), which allowed us to use a binary outcome. We used an AR(1) correlation structure to control for autocorrelation. We used 3 main categorical independent variables: 1) keyboard, which evaluated the difference in overall discomfort when participants used the FSA keyboards compared to the ST keyboards; 2) period, which evaluated whether there was a difference between those who received the ST keyboard first and those who received the FSA keyboard first; and 3) the interaction term, keyboard by period which evaluated the difference in keyboard use between the two periods. In the final model we adjusted for age, average computer use, and health status as these have been significantly associated with discomfort in other studies.

After completing the primary analysis, we completed exploratory analyses to determine the moderating effect of the severity of baseline discomfort on outcomes. We completed these analyses on only the first 5 months of data collection, eliminating the cross over design. We created a baseline discomfort severity score by dichotomizing the baseline WDS into none/mild discomfort (0 to 3) and moderate/severe discomfort (4 to 10) for each body part. We calculated a follow-up discomfort score by taking the mean score of the WDS data collected in the final 4 weeks of the study (month 5) for each body part (neck/shoulder, back, RUE, LUE). We used the Wilcoxon Signed Rank Test to determine if there were significant differences between baseline and follow-up discomfort scores for participants using each keyboard, and a Mann Whitney U Test to compare follow-up discomfort scores between groups (FSA vs. ST). We then evaluated the interaction effect of keyboard by severity by completing a logistic regression with the dichotomized follow-up score (discomfort/no discomfort) as the outcome variable and the interaction effect of keyboard by severity as the predictor variable. Alpha was set at .10 as this was an exploratory study.

The CRF outcomes were also analyzed using GEE linear regressions with AR(1) correlation structure to adjust for the autocorrelation of measurements from each participant. As with musculoskeletal discomfort, we adjusted for age, average computer use, and health status with no significant change in results. At the end of the study participants indicated which keyboard they preferred.

To determine if there were significant differences in wrist and finger kinematics at follow-up we used a mixed model that was fit to each kinematics parameter (as the outcome) for each hand (right/left). We included two fixed effect variables, keyboard and group, and a random intercept to account for within participant correlation as there were two follow-ups for each participant. Group was included to adjust for the effect of group membership (Group 1 versus Group 2).

To determine if there were significant changes over time, we calculated the difference between the differences. We subtracted the baseline from the follow-up score for each keyboard (ΔFSA and ΔST). We then calculated the difference between ΔFSA and ΔST and completed a one sample t-test. Results were stratified by group. We examined associations between baseline discomfort and postures on the flat keyboard by calculating Spearman rho correlations.

Results

Eighty-five participants enrolled in the study, 44 in ST/FSA (Group 1) and 41 in FSA/ST (Group 2). Although only 70 participants completed the entire year long data collection period (38 in ST/FSA and 32 in alternative/ST; 18% attrition rate), we had sufficiently complete data from 77 participants for longitudinal data analyses. We completed kinematics data analyses on 40 participants.

The sample were primarily female, mean age 44 years (SD = 12.4 years), and slightly overweight (BMI = 26.9, SD = 5.8). Participants came from a broad variety of departments and jobs at the University of Pittsburgh, including faculty, graduate students, and administrative assistants. They reported an average of 6.2 hours per day of computer use, and a majority typed moderately fast to fast. Ninety-three percent of the sample reported discomfort for the neck, 85.7% reported discomfort in the back, and 89.6% and 59.7% reported discomfort for the right and left elbow/forearm/wrist/hands respectively. There were no significant differences between groups at baseline.

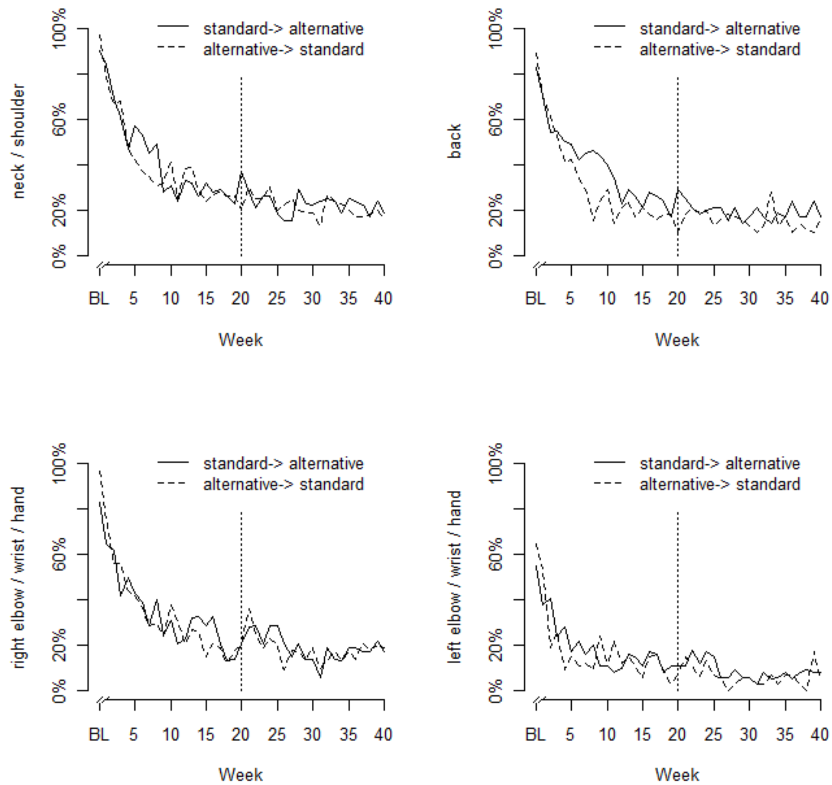

Figure 3: Weekly percentage of participants reporting discomfort for each body area for each keyboard during study period. BL is baseline week. There were no significant interaction effects for any model. The models were adjusted for age, average computer use and health status.

Aim 1: The effectiveness of FSA keyboards at eliminating discomfort over 5 months.

There were significant differences in the percentage of participants reporting that they did or did not have discomfort for the neck and back for the main effect of period, with the greater proportion reporting discomfort in period 1. There were no significant differences for the main effect of keyboard or for the keyboard by period interaction for any of the body areas (Figure 3), indicating that both keyboards, FSA and ST, were equally effective in eliminating discomfort.

Our exploratory analyses of the moderating effect of baseline discomfort suggested that participants with more severe pain at baseline were more likely to eliminate pain using the FSA keyboard than the ST keyboard. When discomfort severity was not included in the assessment, both groups significant improved over time, but neither improved more than the other. However, the interaction between keyboard and baseline severity was significant for the neck/shoulder (p = .002), RUE (p = .06) and LUE (p = .05). In all cases, those using the FSA keyboard had follow-up discomfort scores that were similar to each other regardless of whether they had none/mild or moderate/severe baseline scores. Those using the ST keyboard, however, had much higher follow-up scores for those who had moderate/severe baseline discomfort than those who had none/moderate baseline discomfort.

Subjective perceptions of keyboards: Subjective perceptions of the FSA and ST keyboard as rated by the CRF favored the ST keyboard. One item on the CRF showed significant improvement for the main effect of period; regardless of keyboard, participants found their keyboard less awkward to use in period 2. There were several significant main effects for type of keyboard. Participants rated the ST keyboard as significantly better than the FSA keyboard for items related to usability (e.g. “this keyboard was [not] awkward to use”; “the keys on this keyboard were smooth and easy to use”). There were no significant interactions for the CRF, indicating, that participants’ initial perceptions of the keyboards did not change significantly while using them. On their final rating of the keyboards, participants were asked to identify which keyboard they preferred. Sixty-six responded, and they were equally divided in their preference: 32 preferred the ST keyboard, 33 preferred the FSA keyboard, and one preferred the original board.

Aim 2: The neutrality and stability of postures during keyboard use.

Neutrality of typing kinematics: There were significant differences in postures between the ST and FSA keyboard at follow-up for pronation/supination, wrist flexion/extension and ulnar/radial deviation, and MCP flexion/extension and ulnar/radial deviation. Wrist and forearm postures were significantly more neutral for participants using the FSA keyboard. However, MCP flexion/extension postures for the left middle and ring fingers and right/left little fingers were significantly more neutral for participants using the ST keyboard. MCP ulnar/radial deviation postures were significantly more neutral for the left index finger for participants using the ST keyboard (Table 1). Clinically, the FSA keyboard reduced wrist/forearm postures by 4.7 to 7.2 degrees, and the ST keyboard reduced finger postures by 1.5 to 4.3 degrees.

Stability of typing kinematics: There were only two instances where the ΔFSA was significantly different from ΔST, Group 1 right wrist flexion/extension and right middle MCP ulnar/radial deviation. These were associated with small effect size (Cohen’s *D)* favoring the alternative keyboard.

Aim 3: Which postures are associated with lower levels of musculoskeletal discomfort.

Associations between keyboard postures and discomfort were generally non-significant. The only significant associations were between neck discomfort and left wrist ulnar/radial deviation (rho = -.331), and right hand discomfort and left index MCP flexion/extension (rho = .447), left ring MCP flexion/extension (rho = .387), left little MCP flexion/extension (rho = .421), right ring MCP flexion/extension (rho = .329) and right little MCP flexion/extension (rho = .398). For the MCP joints results indicated the greater the MCP hyperextension, the greater the reported RUE discomfort. For the neck, increased neck discomfort was associated with more neutral postures.

Table 1: Comparison of FSA and ST mean joint postures at baseline and follow-up

	Time	H	FSA M	FSA SD	ST M	ST SD	Diff (95% CI) (ST – FSA)	p
Forearm								
Supination/Pronation	Base	L	-86.6	10.9	-84.9	9.5	-1.7 (-5.6, 2.3)	.393
		R	-84.2	10.5	-80.0	12.3	-4.2 (-9.2, 0.8)	.095
	F/U	L	-89.8	8.6	-82.4	11.0	-7.2 (-11.3, -3.2)	**.001**
		R	-84.3	9.4	-78.0	9.4	-6.3 (-9.7, -3.0)	**<.001**
Wrist								
Flexion/Extension	Base	L	24.6	13.0	27.1	13.1	-2.6 (-5.5, 0.4)	.084
		R	26.1	9.6	24.9	10.8	1.3 (-1.5, 3.9)	.345
	F/U	L	26.5	12.4	21.9	13.0	4.7 (1.6, 7.8)	**.004**
		R	27.3	9.8	20.4	10.9	6.9 (4.6, 9.1)	**<.001**
Ulnar/Radial	Base	L	14.0	9.2	7.9	8.9	6.1 (3.0, 9.3)	**<.001**
		R	11.8	7.8	7.7	8.5	-4.1 (-7.0, -1.2)	**.008**
	F/U	L	15.3	8.2	9.1	6.8	6.0 (3.4, 8.7)	**<.001**
		R	14.2	7.4	8.2	8.3	6.0 (3.3, 8.7)	**<.001**
Fingers - MCP Flexion/Extension								
Index	Base	L	-19.5	10.6	-20.0	10.6	0.5 (-1.3, 2.3)	.555
		R	-25.2	9.3	-23.8	9.8	-1.5, (-2.6, -0.3)	**.013**
	F/U	L	-19.0	10.3	-18.7	10.5	-0.5 (-2.3, 1.4)	.614
		R	-24.4	7.9	-22.8	10.3	-1.6 (-3.3, 0.1)	.057
Middle	Base	L	-11.4	10.4	-13.1	10.0	1.7 (0.2, 3.2)	**.028**
		R	-17.4	9.8	-18.0	9.4	0.4 (-0.8, 1.7)	.485
	F/U	L	-10.8	10.5	-13.2	10.2	2.3 (0.8, 3.7)	**.003**
		R	-17.1	8.7	-17.3	10.1	0.3 (-1.4, 1.9)	.754
Ring	Base	L*	-1.1	10.4	-4.6	9.3	3.4 (1.5, 5.4)	**.001**
		R	-7.7	10.4	-9.7	8.0	2.1 (0.2, 3.9)	**.029**
	F/U	L	-0.8	9.7	-4.4	9.4	3.5 (1.8, 5.2)	**<.001**
		R	-7.0	8.2	-8.8	9.4	1.7 (-01, 3.6)	.065
Little	Base	L	-1.9	11.8	-5.9	10.6	4.0 (2.1, 5.9)	**<.001**
		R	-1.7	13.0	-5.9	10.9	4.0 (2.1, 6.0)	**<.001**
	F/U	L	-1.1	11.6	-5.5	11.4	4.3 (2.9, 5.9)	**<.001**
		R	-1.8	12.6	-5.8	12.1	3.9 (2.0, 5.8)	**<.001**
Fingers - MCP Ulnar/Radial								
Index	Base	L	-2.6	4.3	-3.5	4.3	0.9 (-0.6, 2.5)	.241
		R	-4.1	4.7	-4.2	5.0	0.1 (-1.5, 1.7)	.898
	F/U	L	-2.3	4.2	-3.8	4.0	1.5 (0.1, 2.9)	**.039**
		R	-3.8	4.2	-2.7	4.6	-1.1 (-2.4, 0.2)	.096
Middle	Base	L	4.6	5.3	3.6	5.1	1.0 (-0.7, 2.7)	.250
		R	2.0	6.1	0.5	5.6	1.6 (-0.2, 3.5)	.073
	F/U	L	4.9	5.1	3.9	5.1	0.9 (-0.7, 2.5)	.251
		R*	1.6	5.1	2.5	5.1	-0.9 (-2.2, 0.4)	.185
Ring	Base	L	11.5	5.1	11.4	5.1	0.2 (-1.7, 2.0)	.863
		R	12.1	5.4	12.3	5.4	-0.1 (-2.0, 1.9)	.948
	F/U	L	9.9	4.6	11.1	4.7	-1.2 (-2.7,0.2)	.099
		R	11.8	4.9	13.1	4.2	-1.3 (-3.0. 0.4)	.138
Little	Base	L	18.4	6.6	19.5	6.8	-1.5 (-3.3, 1.2)	.348
		R*	20.6	5.1	20.5	6.7	0.1 (-1.9, 2.2)	.900
	F/U	L	17.5	7.9	18.9	6.0	-1.4 (-3.1, 0.3)	.111
		R	18.9	6.7	20.7	4.2	-1.7 (-3.5, 0.1)	.064

*H = Hand; Time = Baseline (Base) or Follow-up (F/U); L = Left; R = Right; Supination/Pronation - negative = pronation, positive = supination; Extension/Flexion - negative = flexion, positive = extension; Ulnar/Radial - negative = radial deviation, positive = ulnar deviation; *Significant interaction effect group x keyboard*

Discussion

Our kinematics data confirmed that our FSA keyboard was effective at reducing forearm and wrist postures, the postures most often studied in previous keyboard kinematic studies. Though significant, these reductions were, on average, quite small; the largest mean reduction was 7 degrees reduction in supination/pronation. The FSA was not effective at reducing finger MCP joint flexion/extension postures; those results that were significant favored the ST keyboard over the FSA keyboard. Our previous study on ergonomic keyboards reported similar results[24], that while FSA keyboards reduced forearm/wrist postures, they increased MCP postures.

The data suggest that, overall, there were no significant difference between the FSA and ST keyboard in their ability to eliminate discomfort in a general population of computer users. Figure 3 demonstrates that the percentage of participants with discomfort dropped swiftly within the first few weeks regardless of the keyboard used, and then remained relatively stable for the remainder of the study. There were no significant differences in the percentages of participants reporting discomfort based on which keyboard they used. The results of this study are confirmed by the surprisingly few studies that have examined the effect of alternative keyboards on discomfort in the workplace[8-10]. These studies, in general found mixed evidence to support the use of alternative keyboards, despite perceptions to the contrary. Due to these mixed results systematic reviews evaluating computer workplace interventions have not strongly support using alternate keyboards to reduce discomfort[14,15].

If improved postures were the mechanism for reduction of musculoskeletal discomfort, as hypothesized by proponents of alternative keyboards, participants should have reduced or eliminated discomfort during FSA keyboard use, and should have maintained or increased musculoskeletal discomfort during ST keyboard use. Instead a similar percentage of participants eliminated musculoskeletal discomfort regardless of which keyboard they were using, and the reintroduction of a ST keyboard did not correspond with an increase in the number of participants reporting any musculoskeletal discomfort. Results of the kinematics data were generally stable. Of note, wrist supination/pronation and flexion/extension were not significantly different at baseline, but were significantly different at follow-up. These results did not cause significant differences between the deltas, but may be indicative that wrist postures improve with use, particularly with the alternative keyboard for flexion/extension. The effect size *D* for these postures were right -0.40, and left -0.41, which are close to a moderate effect.

Anticipating that the limited results of previous studies might have been related to the comparison of different users, we used a cross-over design to thoroughly control for each participant's unique characteristics such as their workstation design, stress levels, and perception of discomfort. These rigorous controls only served to highlight the ambiguous nature of the results of the previous studies; our participants improved regardless of the type of keyboard they used.

Although FSA keyboards were not significantly more effective for our average keyboard user, our exploratory analyses suggested that baseline discomfort may play a role in the effect of FSA keyboards. More participants who had moderate/severe discomfort at baseline eliminated their discomfort when they used the FSA keyboard than those who used the ST keyboard. While promising, these results require further testing.

Considering that the overall results do not favor posture as a strong predictor of discomfort, it is not surprising that there were few associations between posture and discomfort at baseline. Interestingly, those associations that were significant were those for MCP hyperextension; joint postures that are increased during FSA keyboard use. Our previous research on postures during computer keyboard use suggest that over 20% of computer users hyperextend their right/left ring finger MCP, over 20% hyperextend their right little finger MCP, and over 50% hyperextend their left little finger[25]. Further research on MCP digit hyperextension should be completed to understand the effect of this phenomenon on computer related musculoskeletal discomfort and MSD. Our result that decreased ulnar deviation was associated with increased neck discomfort was contradictory to previous research which found that greater ulnar deviation was a risk factor for discomfort.

We hypothesized that participants would prefer the FSA keyboard to the ST keyboard, as Hedges et al. had reported that his participants preferred the FSA design[8]. However, our participants reported that they found the ST keyboard design to be more usable than the FSA keyboard design. These observations remained even after 5 months of use, suggesting that some participants may never have fully acclimatized to the keyboard. Interestingly, despite the preference for the ST keyboard, half the participants indicated that they would prefer to continue to use the FSA keyboard rather than the ST keyboard.

Limitations: Obtaining data from participants using their own keyboard prior to using the study keyboards over a longer period of time would have provided a more precise baseline level of musculoskeletal discomfort. A washout period between the two study periods in which the participants returned to their own keyboards would have allowed participants to return to pre-study levels of musculoskeletal discomfort. After reporting discomfort symptoms for almost a year, participants may have been less precise in their reports at the end of the study than at the beginning. One final limitation of our study was our ST keyboard. Although we chose it because it would not have an effect on posture, it is possible that it did affect some underlying cause of musculoskeletal discomfort, such as force.

Conclusion

The FSA keyboard is no more effective at eliminating musculoskeletal discomfort than a ST keyboard; both equally reduced the proportion of people experiencing discomfort during computer keyboard use. While the FSA keyboard did reduce many of the wrist/forearm postures considered to be risky, these reductions were clinically small. The FSA keyboard generally increased postures for the finger joints, which may also affect discomfort. This study does not support the use of FSA keyboards to eliminate discomfort in all keyboard users. Results of exploratory analyses suggest that those with moderate/severe discomfort may benefit from FSA keyboards, but these results need to be further evaluated.

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Publications

Journal Articles

Baker NA, Xui K, Moehling K, Li Z-M: [2013] Dynamic postures of the transverse metacarpal arch during typing. Journal of Applied Biomechanics e-pub ahead of print.

This article examines postures during computer keyboard typing (Aim 2).

Baker NA, Moehling K: [2013] The relationship between musculoskeletal symptoms and discrepancies between worker anthropometrics and their computer workstation configuration. Work 46:3-10. (doi: 10.3233/WOR-2012-1480)

This article examines the associations between musculoskeletal discomfort and the computer workstation set-up (Aim 3).

Baker NA, Moehling K, Park SY: [in press] The effect of a fixed split-angle keyboard on musculoskeletal discomfort: A randomized cross-over trial. Work.

This article describes the effect of the alternative keyboard on musculoskeletal symptoms (Aim 1).

Proceedings

Baker NA. The relationship between computer-related discomfort and everyday activities. Proc of the 2010 Human Factors and Ergonomics Society 54th Annual Meeting, San Francisco, California, 714-717, September 27 – October 1.

This proceeding examined the limiting effect of computer-related discomfort on everyday activities. It was secondary analyses of the primary data

Baker NA, Moehling, K: [2012] The moderating effect of the severity of baseline musculoskeletal discomfort on the effect of an alternative keyboard: A 5-month randomized clinical trial. Proc of 2012 Human Factors and Ergonomics Society 56th Annual Meeting, Boston, Massachusetts, 648-631, October 22-26

This proceeding described the moderating effect of baseline musculoskeletal severity on the effect of alternative keyboard use (Aim 1).

Baker NA. The effectiveness of alternative keyboards at reducing musculoskeletal symptoms at work: A review. Proc of 2013 4th International Conference of Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management/in the 15th International Conference on Human Computer Interaction, Las Vegas, Nevada, Part II, LNCS 8026. 189-195, July 21-26.

This proceeding provided an overview of the results of the study in context of other literature on alternative keyboard use (Aim 1).

We also completed pilot work on tele-ergonomic workstation set-up. The following articles were published related to this work

Journal Articles

Baker NA, Livengood H, Jacobs K. The reliability and validity of the Computer Workstation Checklist. Work. 2013;45:213-221. doi:103233/WOR-131603

Baker NA, Jacobs K. The feasibility and accuracy of using a remote method to assess computer workstations. Human Factor. 2013;Sept: pub online. doi: 10.1177/0018720813503985

Abstract

Baker NA, Moehling K. The effect of a systematic, personalized computer workstation redesign on musculoskeletal symptoms. Arthritis & Rheumatism. 2012;64(10 supp):S1026-1027.

Program Director/Principal Investigator (Last, First, Middle): Baker, Nancy, A. ScD, MPH, OTR/L

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: The effect of alternative keyboards on discomfort and typing kinematics

Total Enrollment: 84 **Protocol Number:** PRO08030467

Grant Number: 5 R01 OH008961-03

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race

Ethnic Category	Females	Males	Sex/Gender Unknown or Not Reported	Total
Hispanic or Latino	1	0	0	1 **
Not Hispanic or Latino	77	6	0	83
Unknown (individuals not reporting ethnicity)	0	0	0	0
Ethnic Category: Total of All Subjects*	78	6	0	84 *
Racial Categories				
American Indian/Alaska Native	1	0	0	1
Asian	2	0	0	2
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	8	0	0	8
White	66	6	0	72
More Than One Race	1	0	0	1
Unknown or Not Reported	0	0	**0**	0
Racial Categories: Total of All Subjects*	78	6	0	84 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)

Racial Categories	Females	Males	Sex/Gender Unknown or Not Reported	Total
American Indian or Alaska Native	0	0	0	0
Asian	1	0	0	1
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	0	0	0	0
White	0	0	0	0
More Than One Race	0	0	0	0
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of Hispanics or Latinos**	1	0	0	1 **

* These totals must agree.

** These totals must agree.

Inclusion of Children:

No children were included in this study

Materials available for other investigators

Data from the study includes weekly MSD reports as well as demographic data. Kinematics data from all 3 data collection points is available. Data from the study are available on request. Interested persons should contact Dr. Baker at nab36@pitt.edu.

Appendix A: Kinematics Calculations

Local reference coordinate system and planes:

1) Right forearm plane P_{RFA} (coordinate system C_{RFA}): Formed by marker RFA1, RFA2 and RFA3. The origin of C_{RFA} is RFA1. The Z-axis of C_{RFA} aligns to the long axis of the forearm and is determined by $\overrightarrow{RFA1-RFA2}$, directing proximally. The Y-axis of C_{RFA} is determined by $\overrightarrow{RFA1-RFA2} \times \overrightarrow{RFA1-RFA3}$ and direct dorsally. The X-axis is orthogonal to the Z-axis and Y-axis and direct ulnarly.
2) Right hand plane P_{RH} (coordinate system C_{RH}): Formed by marker RH1, RI1, RM1. The origin of P_{RH} is RM1. The Z-axis of C_{RH} aligns to the long axis of the 3rd metacarpal bone and is determined by $\overrightarrow{RM1-RH1}$, directing proximally. The Y-axis of C_{RH} is determined by $\overrightarrow{RM1-RI1} \times \overrightarrow{RM1-RH1}$ and direct dorsally. The X-axis is orthogonal to the Z-axis and Y-axis and direct ulnarly.
3) Thumb rotation plane P_{RT} (coordinate system C_{RT}): Formed by marker RI1, RT1, RT2. The origin of C_{RT} is RT2. The Z-axis of C_{RT} aligns to the long axis of the 1st metacarpal bone and is determined by $\overrightarrow{RT2-RT1}$, directing proximally. The Y-axis of C_{RT} is determined by $\overrightarrow{RT2-RT1} \times \overrightarrow{RT2-RI1}$ and direct dorsally. The X-axis is orthogonal to the Z-axis and Y-axis and direct ulnarly.
4) Ulnar side hand rotation plane P_{RU} (coordinate system C_{RU}): Formed by marker RH1, RM1, RP1. The origin of C_{RU} is RM1. The Z-axis of C_{RU} aligns to the long axis of the 3rd metacarpal bone and is determined by $\overrightarrow{RM1-RH1}$, directing proximally. The Y-axis of C_{RU} is determined by $\overrightarrow{RM1-RH1} \times \overrightarrow{RM1-RP1}$ and direct dorsally. The X-axis is orthogonal to the Z-axis and Y-axis and direct ulnarly.

Data calculation:

1) Wrist movement (FE & RUD & Rotation): The angle between the projection of Z-axis of right hand coordinate system C_{RH} on the YZ plane of the right forearm local coordinate system C_{RFA} and the Z-axis of C_{RFA} is defined as the flexion-extension (FE) angle of the right wrist. The angle between the Z-axis of right hand coordinate system C_{RH} on the XZ plane of the right forearm local coordinate system C_{RFA} and the Z-axis of C_{RFA} is defined as the radial-ulnar deviation (RUD) angle of the right wrist. The angle between X-axis of right hand coordinate system C_{RH} on the XZ plane of the right forearm local coordinate system C_{RFA} and the Z-axis of C_{RFA} is defined as the supination-pronation (SUP/PRO) angle of the right wrist.
2) Thumb plane movement (FE & RUD & Rotation): The angle between the projection of Z-axis of right thumb coordinate system C_{RT} on the YZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is defined as the flexion-extension (FE) angle of the right thumb plane. The angle between the Z-axis of right thumb coordinate system C_{RT} on the XZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is defined as the radial-ulnar deviation (RUD) angle of the right thumb plane. The angle between X-axis of right thumb plane coordinate system C_{RT} on the XZ plane of the right hand plane local coordinate system C_{RH} and the Z-axis of C_{RH} is defined as the supination-pronation (SUP/PRO) angle of the right thumb plane.
3) Ulnar side hand movement (FE & RUD & Rotation): The angle between the projection of Z-axis of right ulnar hand coordinate system C_{RU} on the YZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is defined as the flexion-extension (FE) angle of the right ulnar hand plane. The angle between the Z-axis of right ulnar hand coordinate system C_{RU} on the XZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is defined as the radial-ulnar deviation (RUD) angle of the right ulnar hand plane. The angle between X-axis of right ulnar hand plane coordinate system C_{RU} on the

XZ plane of the right hand plane local coordinate system C_{RH} and the Z-axis of C_{RH} is defined as the supination-pronation (SUP/PRO) angle of the right ulnar hand plane.

4) MCP joints movement (FE & RUD):

i. Index: The angle between the projection of the vector $\overrightarrow{RI1-RI2}$ on the YZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is used to calculate the FE angle of the right index finger MCP joint. The angle between the projection of the vector $\overrightarrow{RI1-RI2}$ on the XZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is used to calculate the RUD angle of the right index finger MCP joint.

ii. Middle: The angle between the projections of the vector $\overrightarrow{RM1-RM2}$ on the YZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is used to calculate the FE angle of the right middle finger MCP joint. The angle between the projection of the vector $\overrightarrow{RM1-RM2}$ on the XZ plane of the right hand local coordinate system C_{RH} and the Z-axis of C_{RH} is used to calculate the RUD angle of the right middle finger MCP joint.

iii. Ring: The angle between the projections of the vectors $\overrightarrow{RR1-RR2}$ on the YZ plane of the right ulnar hand local coordinate system C_{RU} and the Z-axis of C_{RU} is used to calculate the FE angle of the right ring finger MCP joint. The angle between the projection of the vector $\overrightarrow{RR1-RR2}$ on the XZ plane of the right ulnar hand local coordinate system C_{RU} and the Z-axis of C_{RU} is used to calculate the RUD angle of the right ring finger MCP joint.

iv. Pinkie: The angle between the projection of the vector $\overrightarrow{RP1-RP2}$ on the YZ plane of the right ulnar hand local coordinate system C_{RU} and the Z-axis of C_{RU} is used to calculate the FE angle of the right pinkie MCP joint. The angle between the projection of the vector $\overrightarrow{RP1-RP2}$ on the XZ plane of the right ulnar hand local coordinate system C_{RU} and the Z-axis of C_{RU} is used to calculate the RUD angle of the right pinkie MCP joint.